Broadband Acoustic Clutter

Charles W. Holland
The Pennsylvania State University
Applied Research Laboratory
P.O. Box 30, State College, PA 16804-0030
Phone: (814) 865-1724 Fax (814) 863-8783 email: holland-cw@psu.edu

Grant Number: N00014-08-1-0098

LONG TERM GOALS

The long term goal is to improve performance of low-mid frequency active sonar systems against clutter.

OBJECTIVES

The objectives are to identify/understand the mechanisms that lead to clutter and develop models that predict the temporal/spatial/frequency dependence of the observed clutter and background diffuse reverberation.

APPROACH

The experimental approach is based upon exploiting both long-range observations of clutter and short-range, or direct-path observations (seabed scattering and reflection) of the features that give rise to the clutter. Direct path observations offer two significant advantages: a) the uncertainties associated with propagation (through a generally sparsely sampled ocean) are minimized, and b) the measurement geometries are favorable to producing data from which hypotheses about the scattering mechanisms can be directly tested. The theoretical approach for diffuse reverberation was taken and advanced from energy flux methods. This project is part of the Broadband Clutter Initiative Joint Research Project (JRP) including ARL-PSU (USA), DRDC-A (CAN), the NATO Undersea Research Centre (Italy) and NRL-DC (USA).

WORK COMPLETED

A short summary of FY09 efforts include:

1) Developed simplfied approach to propagation and reverberation from range-dependent sediment layers (in the adiabatic approximation). Initially tackled range-dependence in layer thickness, though the approach is extensible to range-dependence in all the geoacoustic properties.

2) Planned and executed long-range and short-range reverberation, scattering, propagation and reflection experiments for the Clutter09 experiment, April 29 – May 31, 2009. A key platform

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Broadband Acoustic Clutter**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Pennsylvania State University,Applied Research Laboratory,P.O. Box 30,State College,PA,16804**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long term goal is to improve performance of low-mid frequency active sonar systems against clutter.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

was an Autonomous Undersea Vehicle (AUV) with a broadband source and towed array, which allowed us to probe spatial scales of variability down to scales of importance for the clutter problem.

3) Conducted calibration of broadband source in towbody in the vertical plane. It turns out that reflection from the AUV contributes to the source signature for integration times longer than about 5 ms.

4) Using the source calibration, demonstrated the ability to accurately measure the broadband seabed reflection coefficient as a function of angle using the AUV, by comparing measurements with those collected previously at the same location using a simpler, already established technique [1]. Ongoing work [2] with colleagues Jan Dettmer and Stan Dosso at University of Victoria is providing the groundwork for quantifying the spatial variability of seabed properties from these data.

5) Continued contributing energy flux reverberation results to the ONR-PMW-120 Reverberation Modeling Workshop. The energy flux solutions compare very well with more sophisticated (i.e., computationally intensive) models, e.g., coupled mode, while retaining enough simplicity to provide insights into the physics of reverberation and clutter.

6) Served as chairman of ONR Applied Reverberation Modeling Board (on the committee were Roger Gauss, David Knobles, John Perkins, and Eric Thorsos). Briefed the HiFast FNC community at a workshop in Austin, TX, August 2009 and conducted initial site visit at ARL-UT to help determine key shortfalls in the operational community relative to reverberation modeling.

RESULTS

Example of ongoing analysis from the Clutter09 experiment

In previous work [3-5], we have observed clutter from mud-volcano (MV) clusters that appears target-like on individual pings and through a tracker. The motivation for studying MVs is that a) MVs are present in many littoral areas around the globe and b) MVs are a representative of a class of “non spatially compact” clutter mechanisms which are considerably more challenging to model than spatially compact ones (e.g., wrecks or isolated rock crops) and thus form a kind of test-bed to develop modeling and signal processing approaches for the general class.

There is strong evidence that scattering mechanism is not the 100m scale mounds, but rather small-scale (5-10m) carbonate chimneys distributed on flanks [3,5]. In that previous work, however, we were unable to spatially resolve the distribution of the carbonate chimneys (even high resolution hull-mounted multibeam data were insufficient to resolve the 5m scales required to isolate them). Thus, in that modeling, we resorted to an assumed statistical distribution (exponential). One of the goals of the Clutter09 experiment was to measure the small-scale feature spatial distribution so that the clutter models can be properly tested (i.e., the goal is to independently measure all of the model parameters) and determine the extent to which they can predict the clutter statistics.

The experimental method that we pursued was to use a broadband source and towed array behind an AUV (see Fig 1). The source was designed to transmitted two simultaneous linear frequency

modulated (LFM) chirps at 800-1400 Hz and 1600-3500 Hz, which yield a down-range spatial resolution of 1.3 and 0.4 m respectively. In the Clutter07 experiment, the source was placed inside the nose cone of the AUV however, our analysis showed for that data, complex source radiation patterns due to interaction with the AUV structure. Based on that experience, for Clutter09 we placed the source in a tow body (1.7 m) behind the propeller cone. The towed array had 4 apertures with spacing of 0.21, 0.42, 0.84, 1.05 m. Each aperture consisted of 32 elements and the first hydrophone of the longest aperture was 10.4 meters behind the source. At the center of each band, the 3 dB beamwidths for the low and mid frequency apertures (with Hanning shading) at broadside are 8 and 7 degrees respectively. By towing source and receiver close to (10-20m above) the seabed, direct-path scattering observations of the carbonate chimneys were possible out to ranges of 140m (cross-range resolution of less than 17m). Beyond that range, multipaths were present. For the first analysis, we have restricted our attention to ranges where only the direct path (source to seabed to receiver) was present.

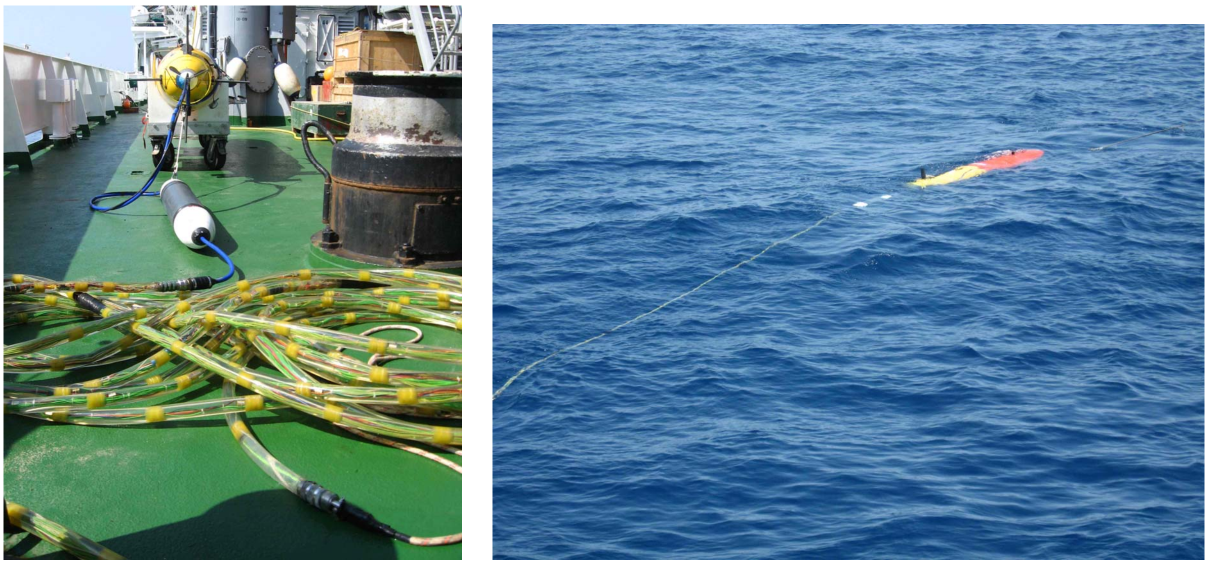

Figure 1. Photograph of Ocean Explorer (OEX) AUV with source (cylindrical tow body) and towed array on deck of the R/V Alliance and on the sea surface.

Figure 2 shows 1600-3500 Hz seabed scattering data from the 0.21m aperture with a source-receiver height above the seabed of 18 m (water depth was ~165m) in an area where there were few/no seabed features. Due to the proximity of the source and receiver to the bottom, some of the region of interest is in the near-field, thus the data were beamformed using a focused (or spherical wave) beamformer developed by Reg Hollett at NURC. The strong return at about 140m radius on the broadside beam (near the edge of the figure) is from the sea surface reflection. The direct blast is seen on the forward end-fire beam (heading is approx northeast). Scattering from a MV is shown in Fig. 3, where highlights related to slope enhancements are seen at close ranges and then strong small-scale scatterers to the north-northwest edge of the MV. This position corresponds to the location of observed carbonate chimneys from sidescan data (shown in the right-hand image). The array has a left-right ambiguity, which was resolved here by analyzing data on a perpendicular track (not shown).

Our initial analysis has shown that the experiment design is capable of detecting small-scale (5-10m) seabed features that lead to sonar clutter. The data will be used to a) map the spatial distribution of the

features, b) quantify the feature scattering kernel, as functions of frequency and 3 cardinal angles, c) measure the background scattering kernel and d) determine the seabed geoacoustic properties using the reflected signal on the towed array.

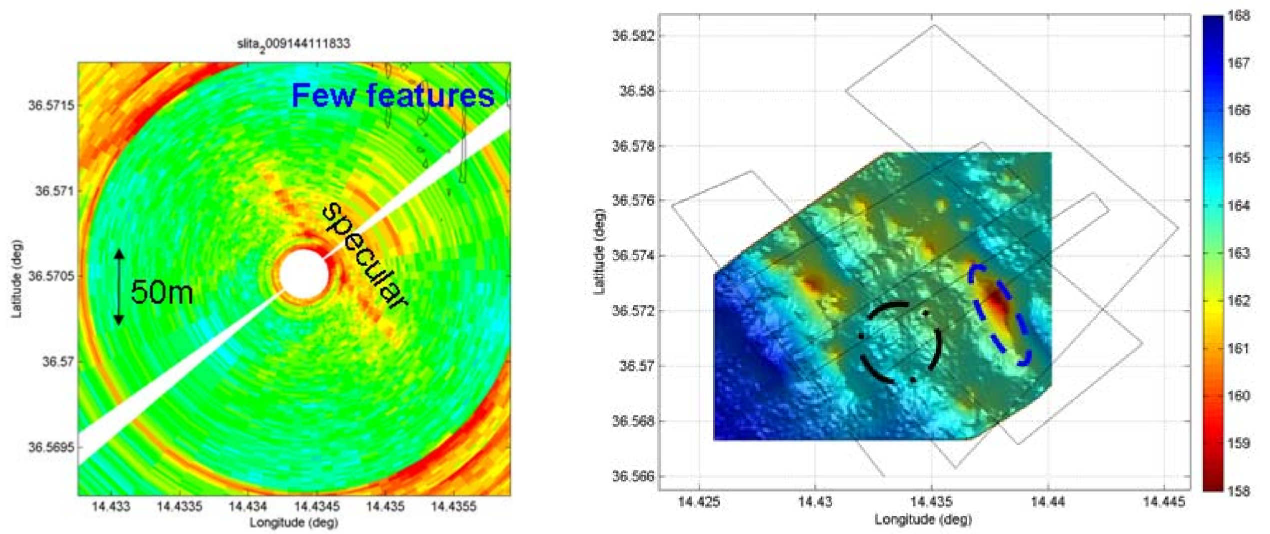

Figure 2. 1600-3500 Hz seabed scattering data in a region of no/few seabed features; data are plotted in dB with a varying gain of 15 log(range) and a color dynamic range of 60 dB. The map to the right shows the data location (black dashed circle) overlaid on multibeam bathymetry. The blue dashed line is the extent of a nearby mud volcano.

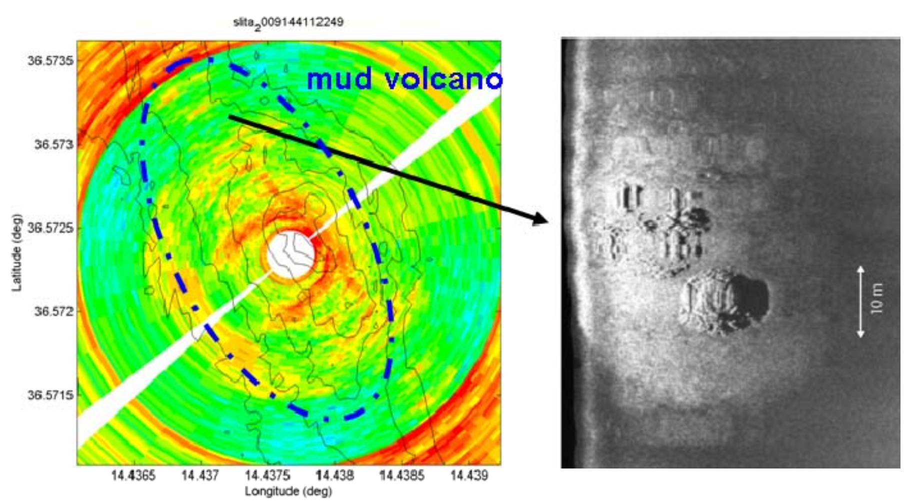

Figure 3. 1600-3500 Hz seabed scattering data in the vicinity of a mud volcano (MV) whose spatial extent is shown by the dashed blue ellipse (see Fig 2 map). Note the strong scattering features on the north northwest edge of the MV, which appear to correspond to carbonate chimneys observed by sidescan sonar.

IMPACT/APPLICATIONS

The importance of these results is that they provide increased understanding of the mechanisms associated with sonar clutter in shallow water. The statistical characterization of these features will lead to clutter models that can be used in signal processing algorithms to predict and reduce the impact of clutter. The results will also be extremely important for training/simulation such as that being developed under the ONR HiFAST FNC and SAST programs.

The modeling approaches may also be useful for transition to the HiFAST/SAST programs inasmuch as they are extremely computationally efficient.

Success of the AUV measurement technique will open the door to 1) measuring small-scale features that lead to sonar clutter 2) measurement of spatial variability (geoacoustic range dependence) at horizontal length scales of order $10^{1\text{-}2}$ m and vertical length scales of 10^{-1}m for propagation/reverberation modeling, 3) measurement of high fidelity scattering dependence on angle and frequency, important for both sophisticated state-of-the-art reverberation model development and providing key data and measurement technique for development of a bottom scattering database.

TRANSITIONS

The seabed scattering data from this program have been transitioned to the PMW-120 Ocean Bottom Characterization Initiative (OBCI, Marcus Speckhahn, program manager) for development of a seabed scattering database for the Naval Oceanographic Office. The scattering data have already been key to the determination of which modeling approach to use for database construction.

RELATED PROJECTS

PMW-120 OBCI Program: Measurement results and techniques developed in this program are being transitioned to the survey community and also to the design of the 1st generation Naval Oceanographic Office bottom scattering database.

ONR Quantifying Predicting and Exploiting (QPE) Uncertainty: data/methods for quantifying geoacoustic variability and uncertainty developed in this project are being leveraged to QPE.

REFERENCES

[1] Holland C.W., Seabed reflection measurement uncertainty, J. Acoust. Soc. Am., 114, 1861-1873, 2003.

[2] Dettmer J., S.E. Dosso, and C.W. Holland, Model selection and Bayesian inference for high resolution seabed reflection inversion, J. Acoust. Soc. Am., 125, 706-716, 2009.

[3] Holland C.W., T. Weber, and G. Etiope, Acoustic Scattering from Mud Volcanoes and Carbonate Mounds, J. Acoust. Soc. Am., 120, 3553-3565, 2006.

[4] Gerig A., and C.W. Holland, Near-specular acoustic scattering from a buried mud volcano, J. Acoust. Soc. Am., 122, 3280-3285, 2007.

[5] Holland C.W., J.R. Preston, and D.A. Abraham, Long-range acoustic scattering from a shallow-water mud volcano cluster J. Acoust. Soc. Am., 122, 1946-1958, 2007.

PUBLICATIONS

Holland C.W. and Ellis, D.D., Shallow water reverberation from a sub-bottom interface: a comparison of modeling approaches, *J. Comp. Acoust.*, 17, 29-43, 2009. [published, refereed]

Dettmer J., S.E. Dosso, and C.W. Holland, Model selection and Bayesian inference for high resolution seabed reflection inversion, J. Acoust. Soc. Am., 125, 706-716, 2009. [published, refereed]

Holland C.W., Fitting data, but poor predictions: Reverberation prediction uncertainty when seabed parameters are derived from reverberation measurements, J. Acoust. Soc. Am., 2553–2562, 123, 2008. [published, refereed]

Holland C.W., Reverberation and clutter from sub-bottom mechanisms, in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 113-122, Sept. 2008. [published]

Abraham D.A. and C.W. Holland, Spatially Compact Clutter, in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 199-208, Sept. 2008. [published]

Nielsen P.L., Harrison C.H., and C.W. Holland, Local bottom characterization using an Autonomous Underwater Vehicle (AUV), in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 345-352, Sept. 2008. [published]

Dettmer J., S.E. Dosso , and Holland C.W., Joint time/frequency-domain inversion of reflection data for seabed geoacoustic profiles, J. Acoust. Soc. Am., 123, 1306-1317,2008. [published, refereed]

Guillon L. and C.W. Holland, Coherence of signals reflected by the seafloor: numerical modeling vs. experimental data, Traitement du Signal (French), 25,131-138, 2008. [published, refereed]

Gerig A., and Holland C.W., Near-specular acoustic scattering from a buried mud volcano, *J. Acoust. Soc. Am.*, 122, 3280-3285, 2007. [published, refereed].

Dettmer J., Dosso S.E. and Holland C.W., Full-wavefield reflection coefficient inversion, J. Acoust. Soc. Am., 122, 3327-3337, 2007. [published, refereed]

Holland C.W., Preston J.R., and D.A. Abraham, Long-range acoustic scattering from a shallow-water mud volcano cluster *J. Acoust. Soc. Am.*, 122, 1946-1958, 2007. [published, refereed]